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SMOOTH COMPLIANT ANTIFOULANT COATINGS

Advanced Conformal Submarine Acoustic Sensor (ACSAS) Outer Decoupler Research and Development

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Interim Technical Report for Flow Noise and Outer Decoupler Workshop, 7-10 June 1982

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Fiber reinforced composites provide a wide array of structural and acoustic properties. The composites may be isotropic and extremely anisotropic and offer considerable flexibility for designing underwater acoustic sensor flow noise outer decouplers. Compliant layers appear to be effective in suppressing flow noise. Effectiveness diminishes with depth, in part because of material compressibility and distortions caused by own ship's speed. Composite materials can be fabricated with high strength and modulus to maintain shape under severe loads.

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SUMMARY

Fiber reinforced composites provide a wide array of structural and acoustic properties. These material composites, composed of a large number of fibers and matrix candidates, allow the engineer to design to practically any desirable sonar sensor requirement.

The purpose of this project is to identify experimental structures for acoustic tests to verify models or to provide additional data to modify associated mathematical models.

It is hypothesized that reinforced fiber material composites provide a means to tailor the structure and properties of a sonar transducer outer decoupler to enhance the signal-to-noise transmission to the hydrophone. Mechanical properties of material composites can ensure optimum acoustic performance of the submarine at all depths and speeds. The versatility of material composites allows the designer and modeler to explore and develop new decoupler systems that respond to the unique requirements of the advanced conformal submarine acoustic sensor (ACSAS).

PREFACE

This document contains material presented by the Presearch Incorporated team at the Flow Noise and Outer Decoupler Workshop. The workshop, held at the Naval Underwater Systems Center in New London, Connecticut, from 7-10 June 1982, was the opening technical seminar for the Advanced Conformal Submarine Acoustic Sensor Program (ACSAS). The Presearch team, consisting of Fiber Materials Incorporated; The Pennwalt Corporation; and Rockwell International, Autonetics Marine Systems Division, was asked to formulate and develop amplifications of ideas and efforts relative to smooth compliant antifoulant coatings applicable to the ACSAS outer decoupler. This request from the Office of Naval Research (ONR) was based upon the effort described in the ACSAS White Paper on Flow Noise and Outer Decoupler submitted to ONR in January 1982 by the Presearch team. The reference to compliance in the context used in this document is a coating that is compliant or transparent to acoustic energy but still maintains good structural properties. If the necessary anisotropic properties are designed into the advanced composite materials, the desirable acoustic properties may be achieved without the structural limitations of the elastomeric materials normally classed as compliant.

In addition to the technical material presented at the Flow Noise and Outer Decoupler Workshop, a projection of recommended technical work related to antifoulant research and development is submitted for ONR consideration. The work projection addresses activities to be undertaken during FY 1983, with some carry-over into FY 1984. These tasks, with associated levels of effort, travel, and material requirements, are submitted to ONR for planning purposes only, and do not represent a commitment by the Presearch team.

CONTENTS

LIST OF ILLUSTRATIONS

SMOOTH COMPLIANT ANTIFOULANT COATINGS

1. OUTER DECOUPLER DESIGN CONCEPTS

1.1 Introduction. Fiber reinforced composites provide a wide array of structural and acoustic properties. The composites may be isotropic or extremely anisotropic. The large number of fibers and matrix candidates allows the engineer considerable design flexibility in developing materials for sonar sensor outer decouplers. This flexibility in design opportunities offers different potential material systems for the outer decoupler. The unique acoustic performance, durability, and antifouling characteristics of each material system must be evaluated in context with Advanced Conformal Submarine Acoustic Sensor Program (ACSAS) requirements to provide the best material for the outer decoupler application.

Compliant layers appear to be effective in suppressing flow noise. Effectiveness, however, diminishes with depth, partially because of material compressibility. Operation at great depths or at high own-ship speeds distorts the outer decoupler and leads to erratic acoustic performance.

This project will identify experimental outer decoupler material structures for acoustic tests to verify models or to provide additional data to modify the mathematical models. Different structures will be designed and fabricated to test new concepts for flow noise reduction, signal transmission, drag reduction, interaction with the large area hydrophone, and a smooth antifouling surface. These outer decoupler designs will rely on input from mathematical models and hydrophone designers

and meet the practical requirements of the marine architect concerned with submarine hull design.

It is anticipated that the outer decoupler will require a smooth hydrodynamic surface that will maintain its structure at all depths and speeds. The outer decoupler must also be capable of withstanding dockside mechanical damage or damage from depth charges. The composite material surface must also be antifouling to minimize drag and flow noise and keep degradation of acoustic signal transmission to the hydrophones within acceptable limits.

Composite materials can be fabricated with high strength and high modulus. These materials can be very tough and will maintain their shape under severe loads if designed properly. The composites can be made highly anisotropic and the use of two or more phases (endless fiber arrangements and fiber density) present almost unlimited design opportunities. Typical fiber arrangements are shown in Figures 1 through 4. These figures are illustrative only, and are by no means a comprehensive representation of all possible arrays.

1.2 Acoustic Design. The most desirable outer decoupler design from an acoustic standpoint is one that will transmit, unimpeded, the far-field acoustic signals that the hydrophones are designed to pick up. The near-field pressure fluctuations associated with flow noise and the structure-borne noise should be attenuated as much as possible. It is recognized that these requirements conflict to a certain degree, but that the flexibility of the composite materials with highly anisotropic properties provides more opportunity to satisfy this full set of requirements.

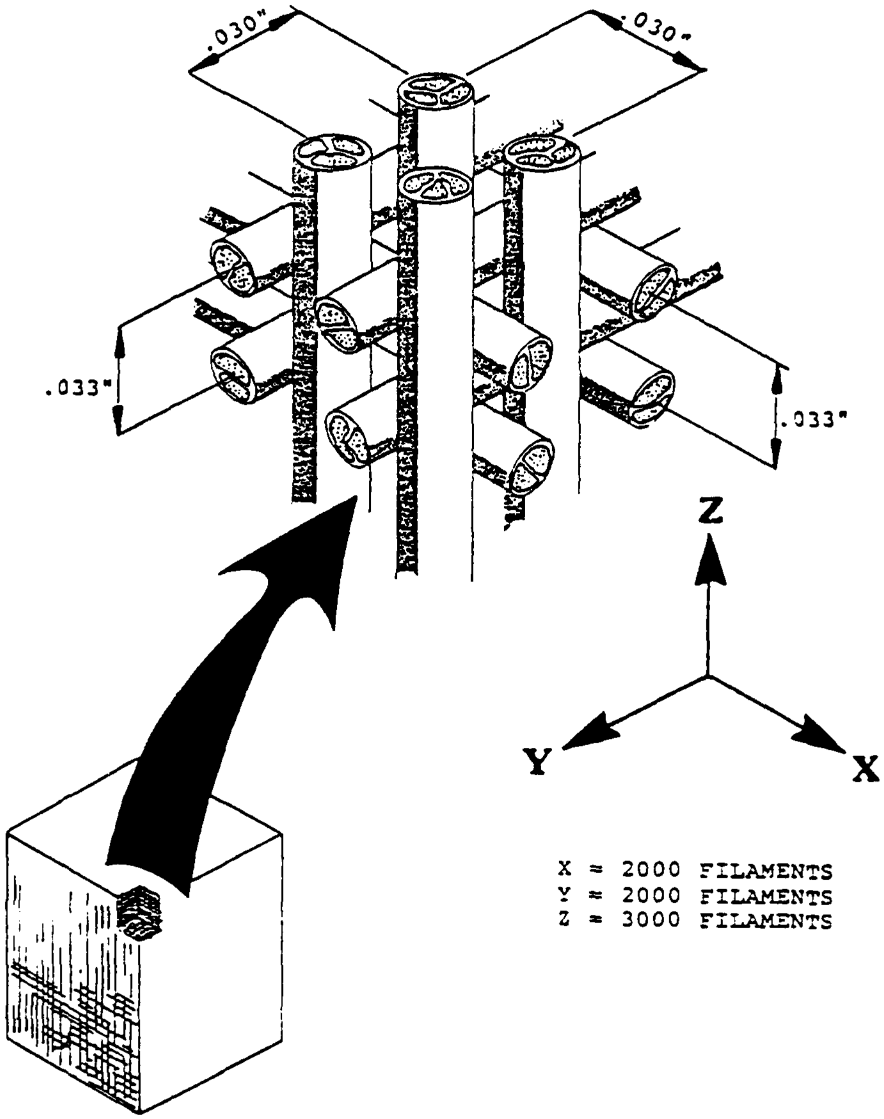


FIGURE 1
2-2-3 CARBON/CARBON CONSTRUCTION

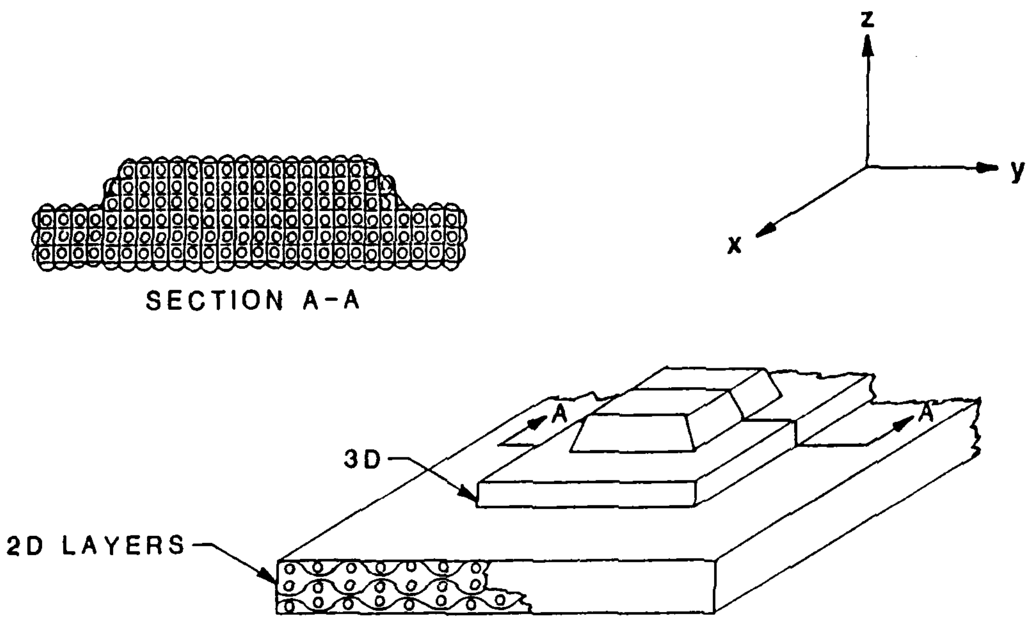


FIGURE 2
2-D/3-D ATTACHMENT PAD TAPES

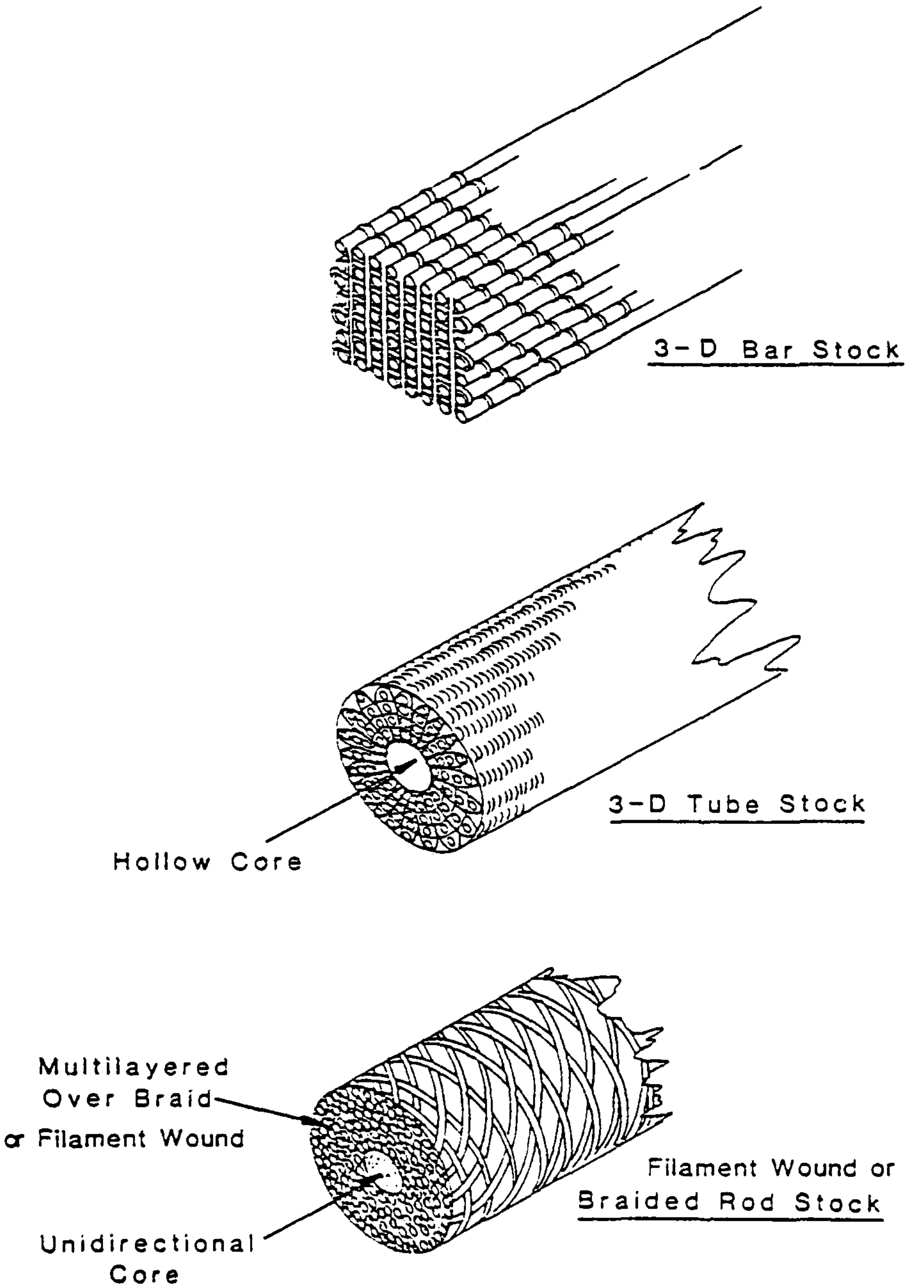


FIGURE 3
STAND-OFF ATTACHMENT POSTS

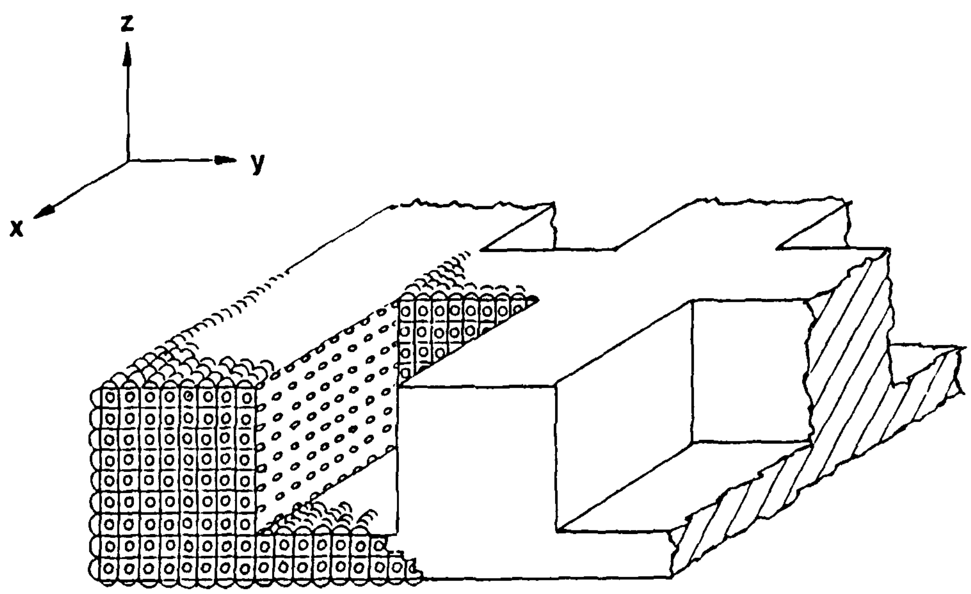


FIGURE 4
3-D WOVEN SKIN AND SUBSTRUCTURE

A limited amount of data is available on the acoustic behavior of composites. However, certain observations have been made. Low frequencies (below 2 kHz) are needed for sonic testing, since higher frequencies are absorbed in carbon-carbon composites. Sound absorption is related to the mismatch of impedance between the fiber and matrix. This may be controlled by modifying the interface, by regulating the surface area of the fibers, and by physical design. The degree of macro-anisotropy in terms of reinforcement geometry influences the frequency range transmitted. The greater the macro-anisotropy, the lower the transmitted frequency range. Three-dimensional composites have been fabricated that have exhibited large differences in longitudinal sound transmission characteristics at various orientations. This phenomenon may be significant in designing an outer decoupler with the acoustic properties required by ACSAS.

Special mechanical problems have been solved by the application of material composites designed to meet the requirements of specific applications. For example, the use of several fibers with different moduli permitted the development of improved golf clubs and tennis racquets that impart more energy to the ball, but avoid transmitting the shock back to the arms. In another application, spallation of nose cones was reduced by designing the composite to modify the shock wave during reentry. Significant progress has been made with uniquely tailored material composites; however, there has been no significant effort to date to establish the basic principles necessary to design optimum composite material systems applicable to acoustic decouplers. The fabrication of composites with excellent structural characteristics and tailored acoustic transmission behavior appears feasible. For example, highly directional sound transmission can be beneficial in discriminating targets, thereby providing a

contribution to improved acoustic performance by the outer decoupler.

Composites also offer a means of using anisotropic behavior to enhance the signal-to-noise ratio. It is possible to manufacture composites in which the extensional modulus (E) is 100 times the shear modulus (G). This is dependent on the three-dimensional design of the composite and is possible because the extensional modulus is dominated by the fibers, whereas the shear modulus is controlled by the matrix.

A wide range of fibers is available, ranging from pliable textile fibers to high-modulus, high-strength carbon and ceramic fibers (see Table 1). The range of properties available in carbon fibers alone is vast. The strength can vary four-fold and the modulus can be selected over an order of magnitude (Table 2).

Similarly, the resin matrices also offer a wide range of properties. The epoxies, urethanes, and copolymers present a family of high performance matrix candidates. In these systems, the resin strength can vary six-fold, and the modulus varies by two orders of magnitude (Table 3).

1.3 <u>Antifouling Coatings</u>. Marine fouling of the hull contributes to drag and flow noise. Antifouling coatings should prevent marine fouling over long periods of time, must not interfere with hydrodynamic or acoustic behavior, and must not be hazardous or environmentally harmful. The application process should be safe, simple, and permanent. Ideally, repairs should be possible while the vessel is afloat. The surface should be smooth and retain that smoothness throughout the operational life of the outer decoupler.

TABLE 1

REINFORCEMENTS

- Fiber Types
  - Ceramic
  - Glass
  - Metal
  - Organic
  - Carbon

- Useful Textile Forms
  - Random
  - Rovings
  - Yarns
  - Two-dimensional fabrics
  - Multidirectional weaves

TABLE 2

TYPICAL PROPERTY RANGE OF COMMERCIAL CARBON FIBERS

	Low Modulus Carbon	High Modulus Graphite
Tensile strength, 10^3 Pa	621	2,413
Tensile modulus, 10^6 Pa	41	345
Density, gm/cm^3	1.5	1.8
Filament diameter, μm	8.5	6.5
Elongation at break, %	1.5	0.6
Thermal conductivity, W/mK	38	70
Electrical resistivity, μm Ohm-m	20	9.5
Longitudinal CTE at 21°C, ppm/K	2	-0.9
Specific heat, J/kgK	925	925

TABLE 3

TYPICAL PROPERTY RANGES FOR EPOXY/URETHANE SYSTEMS

	Rigid System	Flexible System
Tensile strength, Pa	90,000	15,200
Tensile modulus, 10^3	1,290	24
Tensile elongation, %	8	380
Izod notched impact strength, N/m	1.4	17.50
Water absorption, % (24-hr immersion in distilled water)	0.05	0.9
Specific gravity	1.25	1.10

Although several materials are promising, the organo-tin compounds are most advanced (Table 4). The early problems of high toxicity and rapid release are overcome by the synthesis of organo-tin polymers that blend with compliant materials and provide a slow, controllable release. The polymer tin compound may be used to modify the properties of the elastomer or may be applied to the surface. In tests by NSRDC, no fouling was observed after 4 years in warm water. The organo-tin polymer will have excellent bonding to the resin in composites for surface coatings, or it may be blended in the matrix. The versatility of the anisotropic composites accommodates the antifouling coating very well.

2. PROJECTED TECHNICAL EFFORT

The Presearch team recommends a near-term outer decoupler research and development effort composed of three phases. This technical effort will address the specific requirements for the ACSAS outer decoupler during FY 1983 and FY 1984. The three phases, with a brief summary of their content, are presented below.

- Phase 1: Initial Materials Screening
  - Define composite candidates
  - Define antifoulant candidates
  - Define selection criteria
  - Establish laboratory test procedures
  - Conduct limited material tests to support sample selection
  - Evaluate, screen, and select laboratory test samples
- Phase 2: Selected Laboratory Sample Fabrication and Testing

TABLE 4
ANTIFOULING COATINGS

Organo-tin/elastomer blends
- Toxic
- Limited forms
- Limited properties
- Commercially available

Organo-tin polymer/elastomer blends
- Nontoxic
- Can modify elastomer properties
- Long life
- No fouling after 4 years

Organo-tin polymer
- Good bonding to composite
- Can be blended in matrix
- No toxicity
- Smooth surface

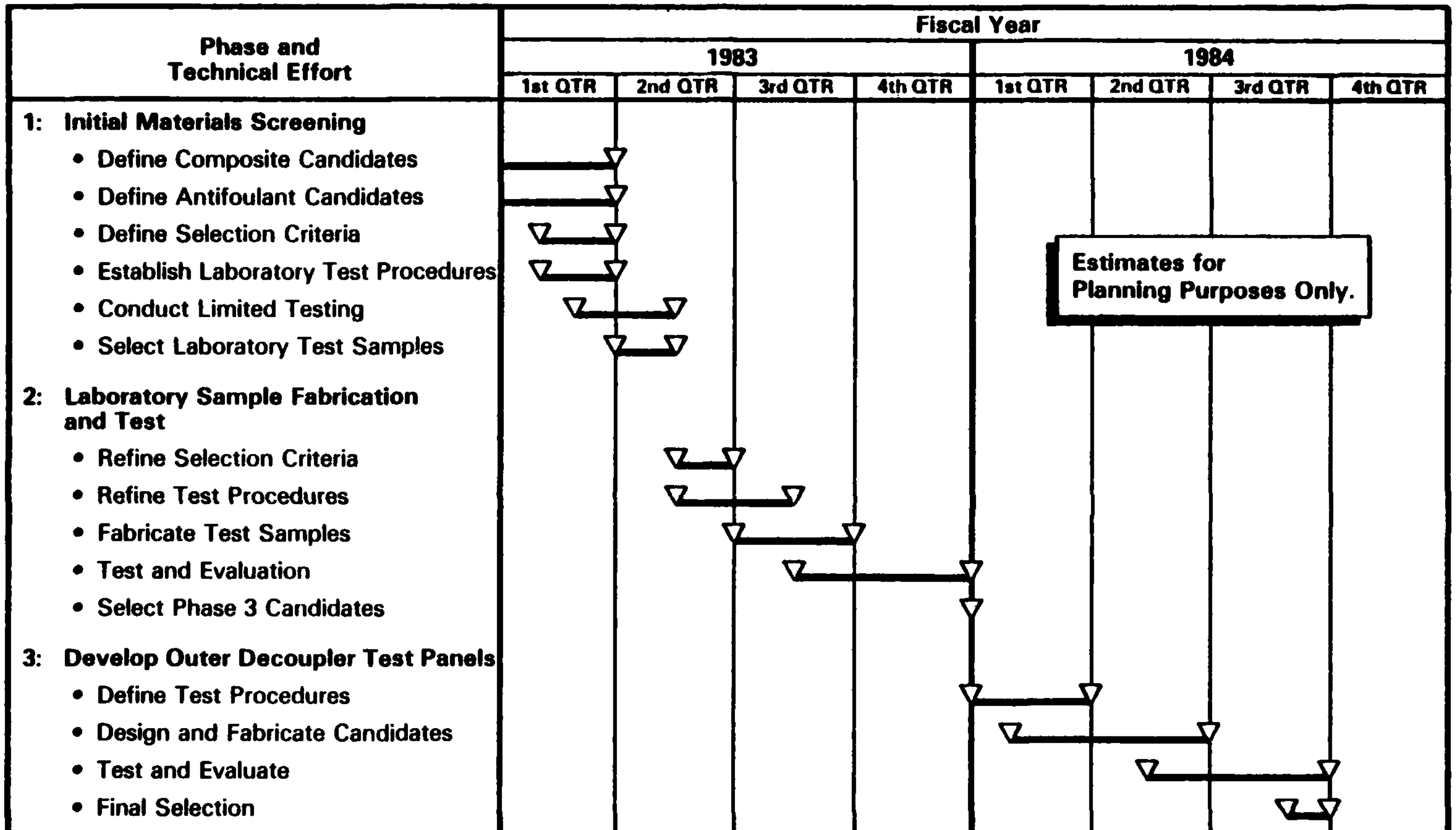
- Refine and expand selection criteria
- Refine and expand test procedures
- Design and fabricate test samples
- Test and evaluate composite material samples
- Select candidates for Phase 3

- Phase 3: Develop Outer Decoupler Test Panels
  - Define outer decoupler test procedures
  - Design and fabricate large test panels from Phase 2 selection
  - Test and evaluate candidate panels
  - Select most viable outer decoupler material combinations.

Each phase is discussed in the following paragraphs. Figure 5 presents a schedule of activities with an estimate of the manpower, travel, and material requirements associated with each phase. It should be noted that the projections for Phase 3 are very dependent upon the number of test panels selected and the complexity of the test procedures required to properly evaluate the selected materials. The Phase 3 projections in Figure 5 are based upon approximately four test panels.

2.1 Phase 1: Initial Materials Screening. The number of composite materials to be considered for the outer decoupler is vast. The purpose of this initial phase is to define acceptable composite candidates that meet ACSAS operational and environmental requirements and to establish a set of criteria for selecting the most promising for laboratory testing.

Composites may be composed of many different fibers and matrices that bind the materials together. Material composites will be tailored to ACSAS acoustic, antifoulant, and structural needs for evaluation and screening. This evaluation will include



	1983 1st QTR	1983 2nd QTR	1983 3rd QTR	1983 4th QTR	1984 1st QTR	1984 2nd QTR	1984 3rd QTR	1984 4th QTR
Level of Effort, man-months per quarter	9	9	11	12	15	15	9	
Travel, $	3,000	3,000	3,000	3,000	4,000	4,000	4,000	
Material Costs, $	2,000	10,000	20,000	4,000	20,000	30,000	—	
Total Estimated Cost, $ ($100,000 per man-year)	80,000	88,000	115,000	107,000	149,000	159,000	79,000	

FIGURE 5

PROJECTED WORK SCHEDULE

a comparison of the new material composites with compliant layers having similar characteristics.

An assessment of new biocidal antifoulant materials developed by the Navy will be addressed for the ACSAS outer decoupler application. It is of fundamental importance that antifouling materials be selected on the basis of compatibility with the outer decoupler and surface characteristics that minimize acoustic distortion, and that they contribute to long-term effectiveness.

In this phase criteria and test procedures for the evaluation of candidate materials will be defined. The applicability and availability of test equipment and facilities in the Navy and private sector will also be identified.

The end result of Phase 1 will be the definition of a set of desired properties of composite materials that weigh the parameters of acoustic, structural, and antifoulant properties. These guidelines will be used in the design and fabrication of test samples in Phase 2.

2.2 Phase 2: Selected Laboratory Sample Fabrication and Testing. In this phase the acoustics, sonar systems, and submarine architectural requirements will be applied to the refinement of the screening process. There are two major tasks in this phase: design and fabrication of test samples and testing. It is anticipated that at least two dozen configurations will be fabricated.

The samples will be chosen to demonstrate the capabilities of composites with different fiber and matrix properties in designed configurations. With a wide range of available properties, it will be possible to provide a range of characteristics for

consideration, including composites, in which the modulus of the matrix can vary from the outer to inner surfaces.

It should be noted that, in addition to the design and fabrication of structural composite materials, these materials will include the incorporation of biocides as an integral part, either as a matrix ingredient or as a coating. The deployment of biocides will depend on the materials used. In some cases the antifoulant may be blended throughout the matrix. In others it will be a coating or a gradient dispersion. The exact deployment technique will be determined by inputs from the chemical and operational experience of the Presearch team.

In parallel with the candidate fabrication process, the team will refine and expand the test procedures. This process will draw on both submarine operational experience and sonar systems knowledge. Specialized laboratory tests will be developed to test the efficiency of each of the performance requirements, such as signal-to-noise improvement, antifouling, change in acoustic characteristics, flow noise generation with time, and many others. These tests, however, must be kept relatively simple and easy to conduct.

The outputs from the performance tests will be evaluated along with many other factors, such as environmental suitability, fabrication impact, logistic support, and maintainability. From these criteria "semi-finalists" will be selected for Phase 3 test and evaluation.

2.3 <u>Phase 3: Develop Outer Decoupler Test Panels</u>. This phase will be similar to Phase 2 in that there will be refinements in fabrication and test procedures. This phase, however, will involve the fabrication of large panels and the conduct of tests

in much more detail and with a small number of prime candidates. Fabrication development will focus on enhancing desirable properties, suppressing less desirable characteristics, and refining the candidates for practical production. Similarly, the test refinement task will focus on real-world testing as opposed to laboratory screening tests.

There are a number of tests considered desirable for the more stringent evaluation needed of the limited number of materials selected during the first two phases. These tests should include an assessment of mechanical coupling as a function of direction and frequency, and determination of the acoustic transmissibility of the outer decoupler. The most directly applicable test would be one in which the outer surface is excited by fluid flow and the coupling measured directly. A full assessment of meaningful tests will be developed during this program in concert with appropriate Navy laboratory personnel and ACSAS team members.

Some of these tests could be conducted on vibration tables utilizing accelerometers. Also, acoustic pools or instrumented lake facilities could be used for acoustic transmissibility tests. Water tunnels, tow tanks, or pop-up test vehicles could be used for the flow excitation tests. These tests will be assessed and acceptable procedures selected. The expertise of the entire Presearch team will be used, and the team will work closely with the Navy during this process.

The culmination of Phase 3 will be the actual testing of outer decoupler test panels. It is anticipated that this testing will be performed at several sites, including facilities at Rockwell and Navy laboratories. Upon completion of the testing, a final report with recommendations will be published.